The Intuition of Famous Physicists and Mathematicians.

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Abstract. In this article, we will show how some famous Physicists and Mathematicians were led by intuition to explain phenomena observed in nature by making or assuming, at some point in their research, hypotheses or non-rigorous decisions ("artifices") to overcome difficulties that some experimental observations presented or could present to their works (theoretical or experimental). Others, also driven by strong intuition, perhaps believing that they could show the existence of forces and phenomena not yet observed or explained in Nature, were able to prove them experimentally. ***Key words: intuition.***

(I)Introduction.

Some famous physicists such as the Italian Galileo Galilei (1564-1642), the German Johannes Kepler (1571-1630), the Frenchman Antoine Henri Becquerel (1852-1908; pop, 1903) and the American Robert Andrews Millikan (1868- 1953; PNF, 1923), taken by intuition, made or assumed, at some point in their research, unreasonable hypotheses or decisions ("artifice") to overcome difficulties that experimental observations presented or could present to their work (theoretical or experimental). One could think that they would be small "frauds" if there was deceit in its intentions.[1] Presenting the historical context in which they occurred and their subsequent unfolding will show that, really, there was no deceit. These intuition-guided researchers knew how nature behaves before formulating their theories. They did not bother with some small details of their predictions. The "artifices" would indeed be "short circuits" that they introduced so they could quickly reach final results they knew to be correct. Other physicists such as the Englishman William Crookes (1832-1919), the Dutchman Heike Kamerling Onnes (1853-1926; Pop, 1913) and the Americans Arno Allan Penzias (n.1933; PNF,1978) and Robert Woodrow Wilson (1936; PNF, 1978), also led by a strong intuition, perhaps believing in the existence of forces and phenomena not yet observed in Nature, insisted for many years to finally prove them. Finally, we will cite the American mathematician and meteorologist, Edward Lorenz (1917-2008) who led by intuition discovered the "butterfly effect."

(1) Aristoteles, Galileu and the Bodies Motion.

(1.1) The Movement According to Aristotle.[2]

The earliest observations on the movement of bodies took place in antiquity. Indeed, the Greek philosopher Aristotle de Estagira (384-322 BCE) in his book entitled Physis ("Physics") presented his ideas on the movement. In relation to the attributes (categories) of the beings that are affected by the movement, Aristotle distinguishes four species of movement: 1) according to the essence of the being: generation and corruption; 2) according to quality: change; 3) according to the quantity: growth (accelerated) and decrease (decelerated); and 4) according to the place: natural if it is directed to its natural place (for example, upwards like fire and air, and down like water and earth); and forced or violent, to move away from its natural place by means of an external agent ("force" or "power"). In the continuation of his studies on the movement, Aristotle affirmed that there is a dynamic principle in the movement: - Every moved one is moved by a motor. Thus, in the natural movement a body moves because of its appetite, that is, according to its nature, which is an inner motor. Already a body under a forced movement does it by means of an engine that is strange and contiguous to him. This, said Aristotle, is the case of the movement of a body in the air, because this, being "pushed" to the sides by the body, drives it in its trajectory. Therefore, he concluded, there is only forced movement if there is air, a conclusion that led to the famous apothegm: -*Nature has horror of the vacuum*.

Using these principles, Aristotle obtained the following results:

(1) Whenever a force or power is exerted on a piece of furniture, the ratio of the distances traveled is equal to the ratio of the travel times.
(2) The ratio of the forces exerted on a piece of furniture is equal to the ratio of the distances traveled in the same time interval, provided that these forces have an intensity exceeding a certain limit below which they cannot act.
(3) The movement of a body through a resistant medium, in addition to being proportional to the force that produced it, is also inversely proportional to the resistance of the medium considered.
(4) Bodies move differently from each other because of excess weight or lightness.
(5) A heavy body falls faster than a lightweight.
(6) The speed of a free fall body is proportional to its weight.

(1.2) Motion according to Galileo Galilei. [3]

Continuing the historical context, these works of Aristotle on the movement were studied by Galileo (1564-1642) in his book De Motu ("The Movement"), written between 1589 and 1592, while teaching at the University of Pisa. In this book, Galileo examined the possibility of another movement that was not one of the two Aristotelian movements - natural and violent - which he called neutral. As an example of this new type of movement, it was stated that the rotation of a body in a vertical plane does not fit into these two types of Aristotelian movement, since it is now above and below the horizon. However, the Aristotelian thesis (above) on movement and in particular on the free fall of bodies was definitively refuted by Galileo in his book Discorsi and Dimostrazione Matematiche intorno a Due Nuove Scienze ("Discourses and

Mathematical Demonstrations Around Two New Sciences "). [3] In this book, Galileo geometrically approached the laws of body balance - his first Science (now known as the Resistance of Materials) - and the laws of motion - his second Science (Kinematics). Initially, he studied uniform and evenly accelerated motion and then applied them to the free fall of bodies, to the motion of bodies in inclined planes, to the motion of the pendulum, and to the movement of projectiles. In the free fall of the bodies, he discovered his celebrated laws:

(1) The velocities (v) of bodies in free fall are proportional to the times (t) spent in the fall, that is, $v \alpha t$.
(2) The spaces traveled by bodies in free fall are proportional to the squares of times spent in describing them, that is, $s \alpha t^2$.

On the other hand, in his investigation of the movement of bodies in smooth inclined planes (without friction and considered placed in the vacuum), Galileo observed that the times spent in the descent of a body along the inclined plane in its free fall from the top of the plane , are proportional to the values of their length (ℓ) and their height (h). In the continuation of this study, Galileo showed that if a is the acceleration of the body along the plane (of slope β) for which one has: $\sin \beta = (h/\ell)$ where g is the acceleration of gravity of a body in free fall (in vacuum), then: $a = g \sin \beta$. From this expression it is easy to conclude that if the plane is vertical ($\beta = 90^o$), $a = g$, since $\sin 90^o = 1$. As this expression does not depend on the mass of the body, it is known as the famous statement of Galileo: *-In vacuum, all bodies fall with the same acceleration!*

(1.2)Time Measurements.

Galileo used an ingenious method to measure the times in his experiments.[3] Thus, considering the clepsydra (water clock) used in antiquity as a model, he perfected it in the following manner: he took a vessel of great transverse dimensions, made a tiny hole in its bottom, and put a certain amount of water flowing through it hole to a scale. Because of the large dimensions of the vessel, practically the height of the water level remained unchanged, so that the time spent in the flow was proportional to the weight of the water that reached the balance. However, as Galileo wanted more precision in his measurements of time, he then used the period of a pendulum, whose first laws he discovered when observing the mass at the Cathedral of Pisa, that the period of oscillations of a candlestick placed in movement did not depend on the fact that such swings were fast or slow. He compared the periods of these oscillations by counting his own heartbeat. Galileo performed experiments with pendulums of different lengths of rope and different weights. In them, he "realized" that the oscillations of these pendulums, although of different amplitudes, always take the same time in the complete oscillation (round trip). This, however, *it is not true* as the Dutch physicist Christiaan Huygens (Hague 1629-1695) showed in 1659. [4]

(1.3) Free Fall Times of Bodies.

Let us now see how the "artifice" related to the free fall of bodies enters here. When Galileo made his measurements on the free fall of the bodies, he made measurements of times with pendulum oscillations, nevertheless distinguishing between large and small arches, since he came to (a) and (b), and (b), and (c), we have to consider α between 500 and 600. According to the work of Huyghens, [4] the oscillation times are much smaller for small angles than for larger angles. 1979) [1] these measures by Galileo "suggest that he did not actually carry out all the commuting experiments he declared." This would then be a "device" of Galileo ...

(2) Geocentrism, Heliocentrism and Kepler.

(2.1)Geocentrism.

It is quite probable that the first systematic observations of the celestial phenomena happened in Babylon and in Nineveh, two cities located in Mesopotamia (today, a part of Iraq), cities that existed thousands of years before Christ (a.C.). These observations were made by priests of these city-states, who had a habit of observing the motions of the Moon, the Sun, and the planets [Mercury, Venus, Mars, Jupiter, and Saturn] and the "fixed" stars. As the Sun "appears" at the beginning of the day and "disappears" at its end, everything indicated that it "turned" around our planet Earth), and so the so-called geocentric models (having the Earth as the center) were developed, Since antiquity, the main one was formulated by the Greek astronomer Claudius Ptolemy (85-165 BC),[5] to explain the movement of the planets and their irregularities (eg, retrograde motion, non-circular planetary orbits, variable planetary velocities, Mercury and Venus always observed near the Sun, etc.). This work of Ptolemy, composed of 13 volumes, was translated by the Arabs, around the 9th century AD, then called Al-Magisti or Almagest ("The Great Treaty"). In this geocentric model of Ptolemy, the circular planetary orbits centered near the Earth: the "equant".

(2.2) Heliocentrism.

As the irregularities in the Geocentric model were becoming increasingly difficult to explain, the heliocentric models (the Sun being its center) were also formulated, also since Antiquity, and its main representative was presented by the Polish astronomer Nicholas Copernicus (1473-1543)[6] in his manuscript Commentariolus ("Little Comment"), probably written in 1510. It is interesting to note that this book circulated only among his students and friends, among whom was the Austrian mathematician and astronomer Georg Joachim von Lauchen (Rheticus) (1514-1576). In this book, in analyzing Ptolemy's geocentric model, Copernicus criticized the concept of the equant because it conflicted with "the rule of absolute motion" according to which everything should move in uniform rotation motion around the center of the world which was close to the Sun. But this was not the case in the Ptolemaic model, for in this the planets also rotated in circular orbits, but the rotation was uniform with respect to a point which did not coincide with the center of the circle.

In 1543, stimulated by Rheticus, Copernicus published his famous book De Revolutionibus Orbium Coelestium ("From the Revolutions of the Celestial Bodies"), in which he presented the following postulates that characterized his heliocentric planetary model (or heliocentric model of Copernicus):

(1) The basic metaphysical principle was that of the perfection of circular motion;
(2) The center of the Earth was not the center of the Universe, but only the center of the lunar sphere;
(3) The center of the world was near the sun;
(4) It is the Earth and not the fixed star sphere that revolves around its axis, every 24 hours;
(5) The distance Earth-Sun is much smaller than the distance Sun-Fixed Stars.

Copernicus's heliocentric model naturally explained the retrograde motion of the planets as being due to their velocity relative to Earth. Thus the reason that the retrogradation of Mercury and Venus only occurs when they are in conjunction is due to their greater velocity; and the reason for the retrogradation of Mars, Jupiter and Saturn only occurs in opposition, is due to their lower velocity, also in relation to Earth. In addition to this explanation, Copernicus determined the scale of the solar system, in Astronomical Unit (AU), that is, the distance Earth-Sun: Mercury ~ 0.3776 AU; Venus ~ 0.7193 AU; Mars ~ 1,5198 AU; Jupiter ~ 5,2192 AU; and Saturn ~ 9.1743 UA. It should be noted that Copernicus also had to use 48 epicycles to explain the various observations on the motions of the planets and the Earth itself, since he considered that the planets described only uniform circular motions around the Sun. Note also, that to justify the reason for not observing any parallax (apparent displacement of a star in the sky by virtue of two observations of the same, in different places) annually of the fixed stars, Copernicus used his fifth postulate, and the deficiency of the astronomical instruments for measure it.

The non-observation of stellar parallax was also the reason why the Danish astronomer Tycho Brahe (1546-1601) [7] did not accept Copernicus's heliocentric model. In view of this, and for this to contradict the Bible he presented in 1574 his own model: Tycho-Brahe's geo-heliocentric model:

Earth standing and spinning around it were the sphere of fixed stars, the Moon and the Sun; this, in turn, carried around the other planets.

(2.3) Kepler Heliocentric Model.

In 1595 Kepler [8] the German astronomer Johannes Kepler (1571-1630) [8] sought a mathematical demonstration of Copernicus's heliocentric model, since he had learned it from German astronomer Michael Maestlin (1550-1631). Thus, on July 9, 1595, when he placed a triangle between two circles, he realized that the ratio between the radii of these circles was the same between those of the orbits of Jupiter and Saturn. In view of this result, he tried to inscribe other flat geometrical figures between the orbits of the planets. As such a model did not fit with that of Copernicus, Kepler then proceeded to the regular Pythagorean-Platonic solids: tetrahedron (4 faces), hexahedron (cube: 6 faces), octahedron (8 faces), dodecahedron (12 faces) and icosahedron 20 faces). [8,9] Initially, he inscribed only the cube among the spheres of the planets. However, when comparing the relation between the rays of these spheres and the distances of the orbits of the planets given by the model of Copernicus, verified that there was a great discrepancy. Then he made another attempt, leaving the cube between the spheres of Jupiter and Saturn and the cubes between the spheres of Mars and Earth, Earth and Venus, Venus and Mercury were respectively replaced by the dodecahedron, icosahedron and octahedron. Relating now the rays of these spheres to the Copernican planetary distances, he found that the discrepancy had diminished, except for Mercury, whose sphere tangent to the octahedron did not explain its movements. Thus, it had to appeal to an "artifice",[10] that is, to inscribe the corresponding sphere of Mercury in the square formed by the four median edges of the octahedron. [8,9] In view of this partial success, Kepler continued to improve his mathematical model more and more. Thus, it replaced each sphere by two, where the radius of the smaller was the smallest distance of the planet to the Sun and the greater radius, consequently, the greater orbital distance.

After much improvement, we can see in references 8 and 9 and others mentioned there the famous heliocentric model of Kepler. In this, the "artifice" introduced in a given moment of the searches disappear.

(3) Becquerel and the Radioactivity.

In 1895 the German physicist Wilhelm Conrad Roentgen [11] (1845-1923; PNF, 1901) who was interested in the luminescence [12] that the cathode rays provoke in certain chemicals discovered a new species of rays that he called of X-rays.[14]

At the session of January 20, 1896, the French Academy of Sciences, French mathematician and physicist Henri Poincaré (1854-1912) presented the first X-ray photographs sent by Roentgen. Present at this session was the French physicist Antoine Henri Becquerel (1852-1908; PNF, 1903).[15] Being a specialist in luminescence (fluorescence and phosphorescence) Becquerel began to perform experiments looking for a relationship between the fluorescent substances and the emission of X-rays by them. He did not find such a relationship, however, he discovered a new physical phenomenon. Indeed, in February 1896, Henri Becquerel observed that uranium-potassium sulfate crystals [containing uranyl uranium oxide (UO2)] were capable of impressing a photographic plate covered with dark paper, the whole being exposed to sunlight. As in his first experiment, he had submitted the set to the sun's rays, so the explanation for the fact that the photographic plate was impressed was that sunlight had caused fluorescence in the crystals with the emission of lightning- X which, in turn, crossed the dark paper that enveloped the crystals, thus going to impress the photographic plate. In another experiment, carried out on May 1, 1896, and this time without sunlight (probably on a rainy day in Paris), the phenomenon was repeated. Becquerel then concluded that the compound emitted certain "rays" thus discovering a new physical phenomenon which became known as "Becquerel's rays" and later "radioactivity".

As he believed that the rays were of electromagnetic origin he was led to make experimental errors such as describing evidence that rays could be reflected regularly, refracted and polarized. It was found shortly after that the rays were composed of α particles (He nucleus), β (electrons) and γ rays. He won the Nobel Prize for the discovery of radioactivity in 1903 along with Pierre and Marie Curie. The wrong interpretation of the nature of the rays did not invalidate its discovery.

(4) Millikan and the Electric Charge.

In reference [1] we see a detailed description of many researches conducted from 1897 to 1906 to determine the elementary electric charge of electrons (e) and the ratio e / m. Robert Andrews Millikan (1868-1953) [16] began his research, circa 1906 at the University of Chicago. On October 9, Millikan prepared a first version of his experiences and sent it to the Philosophical Magazine, which published it only in 1910, volume 19, p. 209. Soon after, on October 23, 1909, at the meeting of the American Physical Society in Princeton, Millikan returned to present the first results of the famous oil drop experiment, [1] which were published in 1909 (PR 29, p.560). In this paper, reporting the above experiment, Millikan presented the following value: $e = 4.69\times10^{-10}$ esu. It should be noted that these articles were not cited by their collaborators, Begeman and Fletcher. On April 21 and May 12, 1910, Ehrenhaft presented to the Vienna Academy of Science new results of experiments on the determination of (e), which were published in 1910 (Anzeiger der Akademie der Wissenschaften / Vienna 10, p. 118, 13, p.815). He performed 300 measures of electrical charge on platinum (Pt) and silver (Ag) particles. The 22 load measurements reproduced by Ehrenhaft are in the following range: $(1.38 - 7.53) \times 10^{-10}$ esu. Thus, it was concluded that charged particles not only have a single or double electric charge but may also have loads between and below these values and, therefore, proposed the existence of sub-electrons and, moreover, that the indivisible electric charge should not exist in nature, at least below the minimum value of 0.9×10^{-10} esu, which corresponds to a fractional value (~ 2/3) of the mean value of $e = 3.0 \times 10^{-10}$esu. That was also obtained by Karl Prezibram in 1910 (Anzeiger der Akademie der Wissenschaften / Vienna 1, p.175), in repeating these experiences. On April 23, 1910, Millikan attended the meeting of the American Physical Society, in which he presented a new value for $e = 4.9016 \times 10^{-10}$ esu, which was published in July 1910 (Physical Review 31,92) and in September of 1910 (Science 32, p.439). In 1911, Millikan (Physikalische Zeitschrift 12, p. 161; PR 32, p.392) and Fletcher (Physikalische Zeitschrift 12, page 202; PR 33, p 107) recorded new results for the value of e . As we saw above, in his 1910 experiments, Ehrenhaft had found fractional values for electric charge: his sub-electrons. Millikan, in his experiments carried out between November 11, 1911 and April 16, 1912, had worked with 140 drops. However, since 82 of them had values below the average, which was as we saw before around 4.7×10^{-10} esu. In 1913 Millikan published results of only 58 drops. He omitted results of measurements of 82 drops and considered the final average electric charge to be: $e = (4.774 \pm 0.009) \times 10^{-10}$ esu. The current accepted value is $4.80320425\ (10) \times 10^{-10}$ esu = $1.6021766208\ (98)\times 10^{-19}$ C. We believe that this omission, without justification, was intuitive because it believed that this would arrive at a more realistic value for the charge of the electron.

(5)William Crookes and the Spiritualism.[17]

In the life of physicists there is a dilemma: either we know all the forces of nature or not. The first alternative is so ridiculous that it really is not worth it or refuting it. Our senses are so limited, so imperfect, that the world escapes us entirely. It may be said that if it were not by chance that a piece of iron had not been placed near a magnetite, we would have remained always ignorant of the attraction of a magnetite to iron. By the end of the 19th century no one suspected, for example, the existence of X-rays, radioactivity, and Hertzian waves. The microwave background radiation of the Universe was only discovered in the mid-20th century, etc. From the beginnings of mankind there are reports of "supernatural experiences" of the existence of "spiritual forces." [18,19] Based on these " experiences "several philosophical and / or religious doctrines were proposed having as basic foundation the affirmation of the existence of the spirit or soul. This is described as the primordial element of reality, having autonomy, independence and primacy over matter. These spiritualistic doctrines are contrary to materialism and date back thousands of years. To show the reality of these forces and entities many unsuccessful works had been done until when Crookes became interested in spiritualism. In 1870 Crookes decided guided by his intuition (as we believe!) That had the obligation to study the phenomena associated with the spiritualism adopting scientific methods. Thus, experiments were carried out to establish conclusively the existence (or not) of a new force, connected with the human organism, hitherto unknown. Based on his experiences for several years Crookes stated, [17,19], for example:

(*1) "These experiments seem to establish conclusively the existence of a new force, connected with the human organism in some unknown way."*

(2) "It is absolutely true that a connection was established between this world and the other."

(3) "It has been thirty years since I published a report of the experiments to show that outside our scientific knowledge there is a Force used by intelligences that differ from the common intelligence of mortals ... I have nothing to portray. In fact, a lot would have to be added to this. " (Crookes, 1898).

Crookes was not alone in that opinion. Other scientists who came to confirm the communication of spirits included Alfred Russel Wallace (1823-1913), Sir Oliver Joseph Lodge (1851-1940), John William Strutt (1842-1919; PNF, 1904) and William James 1842-1910). [17,19]

(6)Kamerling Onnes and the Supercondutivity.[20]

Great advances in the area of refrigeration at very low temperatures were made during the nineteenth century. Superconductivity was first portrayed in 1911 by the Dutch physicist, Heike Kamerlingh Onnes (1853-1926; PNF, 1913), whose great part of his scientific contribution is in the field of refrigeration at extremely low temperatures. Around 1908, in his laboratory in Leiden, he was able to liquefy helium by cooling some samples at a temperature of 1 K. Onnes produced only a few cubic millimeters of liquid helium in those days, but it was a milestone for new explorations in regions of temperatures never before studied. The liquid helium allowed the possibility and reached temperatures close to absolute zero, the smallest possible to reach. As late as 1911, Onnes began investigating the electrical properties of metals in extremely cold temperatures. For it has been known for many years that the electrical resistance of metals tends to decrease when cooled below room temperature, but it was not known to what extent the resistance could fall with the decrease in temperature. Some scientists, like the English physicist William Thomson (1824-1907), believed that the flow of electrons in a conductor would be completely stopped when the temperature approached absolute zero. Other scientists, including Onnes himself, believed that electrical resistance would dissipate. Many also suggested that resistance would decrease steadily favoring better conduction of electricity. At a point where the temperature was very low, scientists realized that there was a leveling in the behavior of the material where the resistance virtually disappeared. The Onnes group then attempted to traverse an electric current through a very pure sample of mercury in the form of wire, and measured the variation of its electrical resistance as a function of temperature. At 4.2 K the resistance simply disappeared, and to the scientists' surprise, there was a current flowing through the mercury wire and nothing prevented its flow, resistance was zero. According to Onnes, *"Mercury had passed into a new state, and which by virtue of its extraordinary electrical properties should be called the superconducting state."* The experimental results left no doubt about the disappearance of electrical resistance and opened the door to a new research area baptized by Onnes of superconductivity. The importance of this discovery in the scientific community was recognized for its economic and commercial potential. For in an electric conductor without resistance theoretically it could transport chains without losses, no matter the distance to be traveled. The Onnes group discovered that superconducting wires crossed by a loop current even after years attached had no loss in flux and could remain active for an inestimable time, calling this phenomenon persistent currents. For his efforts, perhaps in a persistent intuitive pursuit of something he believed to be central, Onnes was referred to the Nobel Prize of Physics (PNF), 1913.

Note for a long time theoretical physicists could not explain superconductivity. This was done only about 50 years later using the second quantization formalism by American physicists John Bardeen (1908-1991, PNF, 1956, 1972), Leon Neil Cooper (n.1930, PNF, 1972) and John Robert Schrieffer (n.1931; PNF, 1972) in 1957. [21]

(7)Penzias and Wilson and the Background Cosmic Radiation of the Universe.[22]

In cosmology, cosmic microwave background radiation is a form of electromagnetic radiation, the existence of which was predicted theoretically by George Gamov(1904-1968), Ralph Alpher(1921-2007) and Robert Herman(1914-1997) in 1948. It is characterized by having a blackbody thermal spectrum with maximum intensity in the microwave range. Basically, microwave background cosmic radiation is the fossil of light, resulting from a time when the Universe was hot and dense, only 380,000 years after the Big Bang. Cosmic microwave background radiation, along with the distance from galaxies and the abundance of light elements, is one of the strongest observational evidences of the Big Bang model, which describes the evolution of the universe. This background radiation is an electromagnetic radiation that fills the entire universe whose spectrum is that of a blackbody at a temperature of 2,725 K. It has a peak frequency of 160.4 GHz, which corresponds to a wavelength of 1.9 mm. It is isotropic up to a part in 100 000. This noise can be understood as a "fossil" of a time when the universe was very new and very hot. The photons generated in the Big Bang (13.7 billion light years ago) have continued to cool since then, reaching a temperature of 2.7 K, and that temperature will continue to decrease as the universe continues to expand. The proposal of Gamow et al. has been ignored for over 20 years. But in the 1960s, Penzias and Wilson worked on installing a large antenna on Bell Telephones, when they noticed that there was a problem, because for any corner they pointed, they found a noise. They thought they were feces of pigeons and cleaned with their own hands the poop of the animals. Have you kept insisting on your intuition? But the noise continued ... When they did not know what to do, they consulted the group of theoretical physicists at Princeton University [Robert Henry Dicke (1916-1997), Phillip James Edwin Peebles (n.1935) (of Canadian origin) , Peter Guy Roll and David Todd Wilkinson (1935-2002)] who worked on the hypothesis that the radiation of a primitive, superconcentrated and superheated Universe would have cooled by the expansion of the same and would now be equivalent to a few degrees above 0 K. This group told Penzias and Wilson that they had unintentionally discovered what many physicists were trying to find, namely the Cosmic Microwave Background Radiation from the Big Bang.

Although the discovery was accidental, they received the PNF in 1978 because of the relevance of the finding and, why not, we would say, due to a strong intuition that impelled them to continue to research ...

(8) E. Lorenz and the Chaotic Dissipative Systems.

The mathematician and meteorologist Edward Lorenz (1917-2008) [24] constructed a simplified mathematical model of how air moves in the atmosphere, arriving at the conclusion that small variations in the initial values of the variables of his model led to very divergent results. This sensitivity to the initial circumstances later came to be known as the butterfly effect. Lorenz published his findings in a seminal paper entitled *Deterministic Nonperiodic Flow*, [25] in which he described a relatively simple system of equations that result in an infinite complexity pattern, the Lorenz Attractor. E. Lorenz did his Ph.D. in dynamic systems under the guidance of Geoge David Birkhoff. [26] By the early 1960s many scientists were developing sophisticated linear methods for weather forecasting. Lorenz intuited that the difficulty in the meteorological forecast would be related to the instabilities of the solutions due to non linearity of the differential equations that describe the models proposed for the evolution of the atmospheric conditions. As the exact equations of these models are not integrable according to Birkhoff's work in 1927, [26] Lorenz obtained numerical solutions for the equations considered and confirmed his intuition by verifying the instabilities of these solutions. Initially, Lorenz considered a finite-dimensional fluid model with 12 equations coupled to describe the atmosphere, with many control parameters he had no choice. Using a computer with a small memory of 16KB, which made only 60 multiplications per second, Lorenz obtained non-periodic solutions for many chosen parameters. When interrupting the time series obtained, he noticed that the number of figures with which he wrote down the values of the variables at the moment of interruption, necessary to later continue the desired numerical integration, realized that the continuations of the numerical series differed if the precision, that is, the number of annotated figures increased. He identified this effect as being the *sensitivity of the solutions to the initial conditions*, that is, solutions with near initial conditions diverge over time. For Lorenz this sensitivity was the manifestation of the dynamic instabilities inherent to the solutions obtained. He concluded that it would be impossible to predict weather conditions for a long time because of the nonlinearity of the analyzed equations, which describe the models considered, and the instabilities identified. The evolution of these instabilities amplified the uncertainties in the predictions obtained from the uncertainties of the initial conditions considered. [27] Later, Lorenz deepened his analysis considering a simpler model with 7 coupled differential equations used in 1962 by Barry Saltzman. He considerably simplified this model by considering particular numerical solutions obtained for 4 constant variables. The evolutions of the remaining 3 variables were determined by the numerical solutions of 3 coupled equations. The set of 3 equations obtained had the lowest number of differential equations required for these equations to be non-integrable and have non-periodic solutions; these three equations are now known as the Lorenz system. [29,30] For this system, Lorenz noted the existence of instabilities of non-periodic numerical solutions.

In his famous article in 1963 [27a] he presented his system of 3 equations and showed that non-periodic solutions were sensitive to initial conditions. After a transient, the solutions tended to a limit set known nowadays as *Lorenz attractor* .[27b] This limit, obtained numerically, was the first unstable, non-periodic solution with sensitivity to the initial conditions, obtained in the literature. Currently, this limit is recognized as a chaotic attractor. [29,30] The discovery of these solutions by Lorenz, from his intuition, is recognized as the first chaotic attractor found in dissipative systems. This result remained for some years without mathematicians and physicists noticing its importance. However, with the ease of access to computers and the expansion of research on chaos that began in the 1970s, this work became one of the best known in this area. Currently, the Lorenz system is widely used as a paradigm for the study of coupled nonlinear equations, bifurcations, and chaotic attractor properties.

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